period of death, and in part to the action of acids on anthocyanin as described below. Many of the destructive changes which take place in the chlorophyll are oxidation processes, the same as occur in the cells of highly colored variegated plants, and physiologically they are not very different from the changes occurring in calathea, caladium, codiæum, etc. The approach of maturity in the leaf, and the coming on of cool weather in autumn, stimulate the production of oxidizing ferments, and the action of these and the acids of the cell sap upon the chromogen, or color contents of the leaves, especially the chlorophyll and anthocyanin, causes many of the brilliant colors of autumn foliage. There is a popular belief that these colors are due to cold weather or frosts; but while frosts, if they are light, hasten the solution and destruction of the chlorophyll, they can not be looked upon as more than hastening changes, which would occur in time without them. Even in the Tropics, some foliage before it matures becomes highly colored, and on the Japanese maples the writer has observed beautiful autumnal colorations in July in the region of Washington.

In practically all deciduous trees, bushes, etc., before the maturing and falling of the leaves, all of the valuable food materials, such as sugars, albuminoids, etc., pass from the leaves through the vascular bundles into the twigs and branches, so that they are not lost to the plant. When the leaves finally fall they are therefore nothing but mere skeletons, containing waste materials. In the passage, especially of albuminoid matters from the leaves to the stems, it is necessary that the materials be protected from the strong action of light, and it is believed that part of the coloration of maturing leaves serves the purpose.

A coloring material, or chromogen, known as anthocyanin, is always present in such cases, and develops beautiful reds when the cell sap is acid, blue when no acids are present, and violet when there is only slight acidity. This, in connection with the disorganizing chlorophyll, causes the various mixtures of yellow, brown, violet, red, orange, etc., of autumnal coloration as described above. In very young leaves of many plants, such as *Ailanthus glandulosa, Juglans regia, Vitis, Cissus,* and many other plants, this same anthocyanin is developed as a protection to the albuminoid materials traveling to the young cells. Such protective colorations have to be distinctly separated from variegations. In evergreen leaves, during the winter, the chlorophyll granules are protected by the development of anthocyanin, forming a brownish or reddish tinge in the cell sap. This is especially prominent in many conifers.

While, as stated above, these protective and in some cases transitory colorations should be clearly distinguished from variegation, it is an interesting fact that they develop when the conditions for active nutrition are unfavorable, and may, in many cases, be produced in maturing leaves by starving the plants or permitting them to become sufficiently dry to check growth.

THE WEATHER BUREAU SEISMOGRAPH.

By Prof. C. F. MARVIN, dated July 1, 1903.

It has always been the policy of the Weather Bureau to require its observers to take careful note of earthquake phenomena of sufficient intensity to be felt at stations, but no specific effort has been made to provide generally the instrumental means by which such phenomena could be automatically recorded and measured. The Central Office at Washington has, however, maintained a simple form of seismograph in operation ever since December, 1892, and recently has greatly improved its equipment by the installation of one of the large horizontal pendulums made by J. & A. Bosch, of Strassburg, and designed after the models described by Omori.[1]

[1] Publications of the Earthquake Investigation Committee in Foreign Languages. No. 5. Tokio, 1902.

The older form of the Weather Bureau seismograph was described by the writer in the MONTHLY WEATHER REVIEW for July, 1895, Vol. XXIII, p. 250.

The new instrument is of a very superior type and gives an accurate record of the movement of the earth at the pendulum in the horizontal plane. At the present time but one of the two pendulums constituting the set has been installed and this produces a record of the north and south component of horizontal motion.

The mechanical principles involved in the construction of a seismograph of this type were first developed and applied to the measurement of earthquakes in the latter part of 1880 by James A. Ewing, then Professor of Mechanical Engineering at the University of Tokio, but now Professor of Mechanism and Applied Mechanics at the University of Cambridge, England. Numerous modifications have since been incorporated in the instrument by Gray, Omori, and others, and in its present form it is well adapted to measure and record all kinds of earthquakes, except, perhaps, the most destructive, and is especially suited to register the feeble, unfelt earthquakes, which frequently occur in all parts of the world.

The instrument as set up to photograph is shown in fig. 1. As actually installed in a small basement room of the Weather Bureau, the separate castings are secured to thick blocks of stone cemented firmly into the concrete floor of the building and projecting but a few inches above the floor level. The heavy casting *A* forms the support for the so-called horizontal pendulum *B C D*. *C* is a massive lead weight, rigidly attached to the conical tubular rod *B*, the end of which, at *B*, terminates in a hardened steel plug, hollowed out cup-wise and highly polished. At this point the pendulum is supported upon a sharp, conical pointed stud of hardened steel fixed to the casting *A*. The remaining support for the pendulum consists of a pair of steel wires, faintly seen at *w w* in the picture. At the weight end these are attached to eyes with a knife-formed inside edge and there engage two studs that project laterally from the mass *C*. At *D* the wires are united to a stirrup, which at the point opposite the wires is provided with a bit of hardened steel formed with a cup-shaped recess and highly polished. Here the stirrup is supported on a sharp, hardened steel cone attached to the carrier *E* forming the summit of the casting *A*. The carrier *E* is provided with several adjusting screws; thus, *a* serves to raise or lower the weight *C* and thus adjust it to a horizontal position, while *b* causes the point at *D* to move away from or nearer to the top of the column, and, finally, a pair of screws, one of which is seen at *c*, gives *D* a lateral motion in the horizontal plane. In short, the pendulum *B C D* is supported at *B* and *D* on sharp steel points and swings, therefore, with great freedom of motion. If the points *B* and *D* are rigorously in a vertical line, the pendulum is in neutral equilibrium and the mass *C* will then remain at rest in any position. For practical work, however, a small degree of stability must be imparted to the mass *C*, otherwise minute changes of temperature and other influences which it is impossible to control will cause the mass *C* to wander about from one position of rest to another. The desired degree of stability is given to the pendulum by means of the screw *b* and the azimuth of the point of rest is adjusted by the screws *c*. The degree of stability is determined by noting the time of vibration of the mass *C*, which can be adjusted to swing as slowly as one complete vibration in thirty or forty seconds. A period of twenty-five to thirty seconds seems to contribute a sufficient stability for practical work.

The whole object sought in this construction is to secure a "steady mass," as it is called; that is, a mass that shall remain quite at rest during an earthquake, notwithstanding that the earth and the supports for the mass are undergoing appreciable vibratory displacements. The kinetic property of bodies utilized in this connection is that which gives rise to the so-

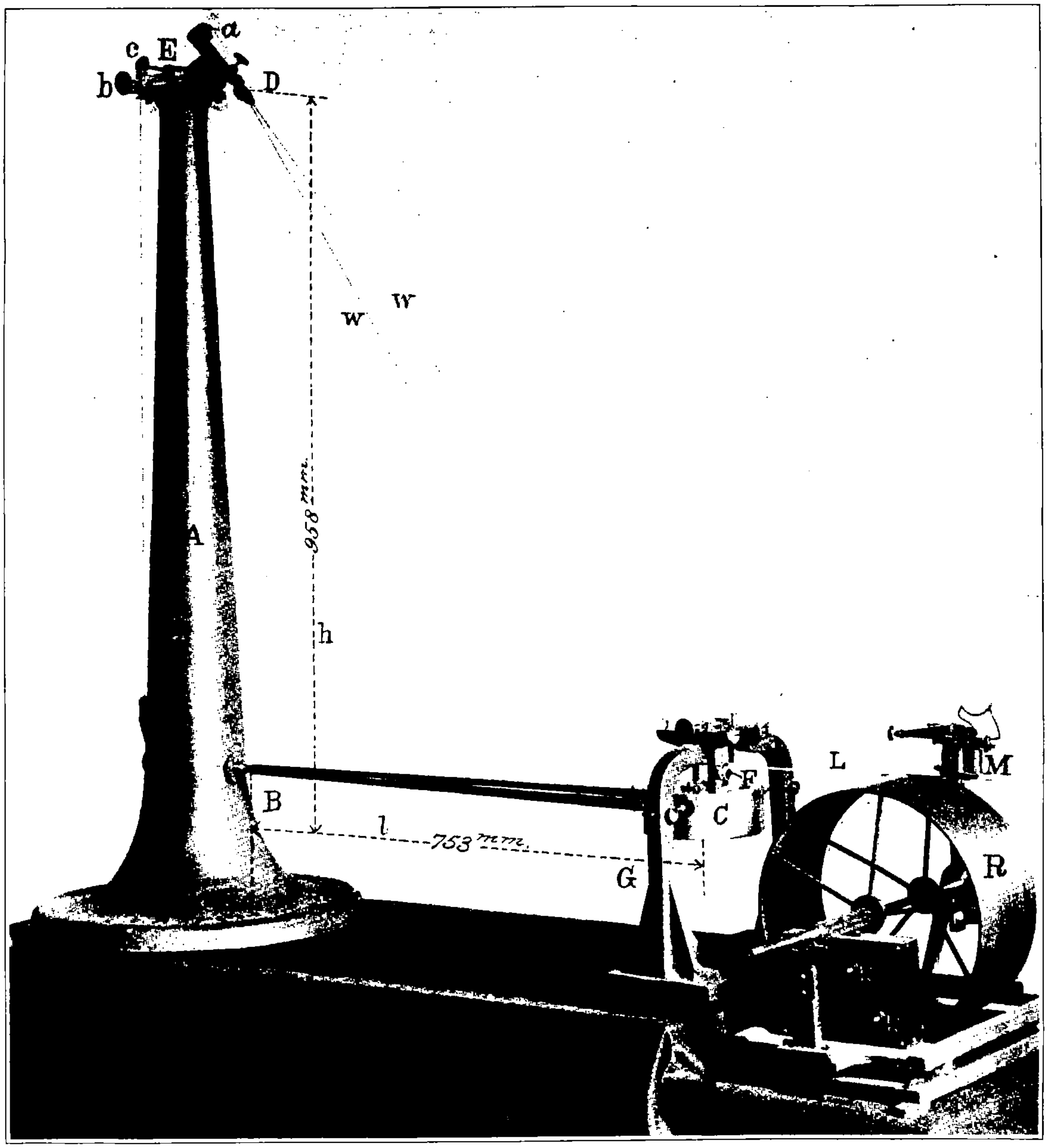

Fig. 1.

called *axis of instantaneous rotation*. Whenever any force is applied in a one-sided fashion to move a body all points of the body will not move in the same manner, in fact, one point, or a line of points, will actually remain sensibly at rest for small displacements. This point, in mechanics, is called the *axis of instantaneous rotation*, or *the center of percussion*.

In the case of the pendulum B, C, D nearly all the mass is concentrated at C and the result is that the axis of instantaneous rotation, or, as we shall call it, the steady line, is at a point very near the center of the mass C. Consequently whenever the support A is displaced horizontally with a vibratory motion, as in the case of an earthquake, the steady line of the mass C will remain at rest for all movements transverse to the plane B, C, D. Motion directly in the line of the strut is communicated, of course, to C, but the registering mechanism is so disposed that such motions produce no record whatever. Although the mass C is very largely displaced whenever the support A is tilted even in the slightest degree in a direction perpendicular to the plane B, C, D, results have nevertheless shown that tilting is not an appreciable feature in earthquake motion, except near the origin of the disturbance, or possibly in the case of large waves. We find then that the steady line of the mass C remains relatively stationary during an earthquake disturbance, and the manner of recording the movement of the earth with respect to this point is shown more in detail in fig. 2.

The magnifying and recording lever shown at L is made of very thin sheet aluminum bent into an inverted trough-shaped section to secure stiffness, and is provided with a conical pointed, hardened steel, axis, d, which is centered and carried in the stirrup F which, in turn, is adjustably but firmly attached to the heavy casting C. The short arm of the lever L is slotted and engages the slender staff f in the manner shown. The staff f is made of hardened steel, with conical pivot points centered in the stirrup F', which is securely attached to the mass C in such a position that the center of the staff f lies in the prolongation of the steady line of the mass C.

The record is traced on a sheet of smoked paper wrapped around the large cylinder R, fig 1. In order that the friction may be reduced as far as practicable at the tracing point, the

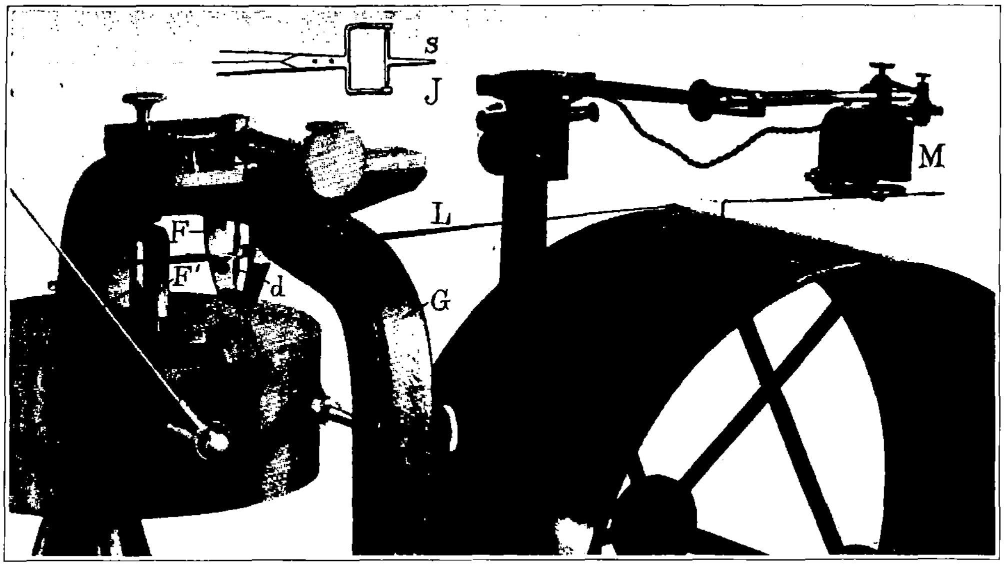

FIG. 2,

coating of soot is made relatively thin and a paper with a highly glazed surface is employed. Much depends also upon the tracing point which is a mere bit of steel, *s*, pivoted to the lever in the manner shown at *J*. The degree of magnification can be adjusted to suit by shifting the carrier or stirrup *F* so as to increase or shorten the distance between the staff *f* and the pivot *d*. Provision is made for a magnification of from 5 to 15 times. A 10-fold magnification seems to give about the best results for feeble earthquakes.

Every precaution must be taken in the construction and mounting of the lever *L* to satisfy the following conditions:

I.—To reduce the mass of the lever to the minimum without serious loss of stiffness and rigidity.

II.—To eliminate friction at the pivots and stylus to the least degree without perceptible shake or lost motion in the pivot points.

III.—To proportion the two arms of the lever so that its axis of instantaneous rotation shall fall at or near the point where the forked end engages the staff *f*. This requirement is of considerable importance if the lever *L* has much mass, but can generally be ignored by keeping the weight down to the lowest possible limit.

IV.—To eliminate every trace of looseness in the pivots and in the forked connection, but at the same time avoid friction.

The record cylinder *R*, fig. 1, is driven at the rate of one revolution per hour, and the axis at one end is cut with a steep screw-thread which shifts the cylinder endwise as it revolves. The stylus therefore traces a helical line on the drum, thus separating the successive portions of the record.

The mechanism at *M* is an electric time marker, the magnet of which is in connection with a circuit closer actuated by a high grade clock. The circuit is closed momentarily once each minute, and causes a finger to mark a time stroke each minute on the trace.

We hardly need to explain that when an earthquake occurs all the parts of the instrument partake of the motion of the earth except the steady line of the mass *C*. This remains relatively stationary in space for horizontal displacements perpendicular to *B C*. The lever *L*, at the point where it engages the staff *f*, likewise remains at rest, hence it follows that the stylus will trace on the drum a magnified record of the lateral displacements executed by the pivot *d*; that is by the ground supporting the instrument.

An example of a record of feeble earthquake is given in the MONTHLY WEATHER REVIEW for March, 1903, on page 126. Since that record was made the sensitiveness of the pendulum has been increased a little, that is, the points *B* and *D* have been brought still closer to the vertical line. The time of a complete vibration of the pendulum is now about twenty-five seconds. A simple pendulum that would vibrate in the same time would require to be nearly 693 feet long.

NOTES UPON THE THEORY AND USE OF THE PENDULUM.

The equation for the time of vibration of a horizontal pendulum is found as follows:

Let l equal distance from the axis of suspension to the center of oscillation of the pendulum considered as a simple pendulum. In other words let l be the radius of gyration of the mass with respect to the axis of suspension. Now as a simple pendulum the time of vibration will be:

$$t = 2\pi \sqrt{\frac{l}{g}}$$

where g is the acceleration due to gravity or whatever force

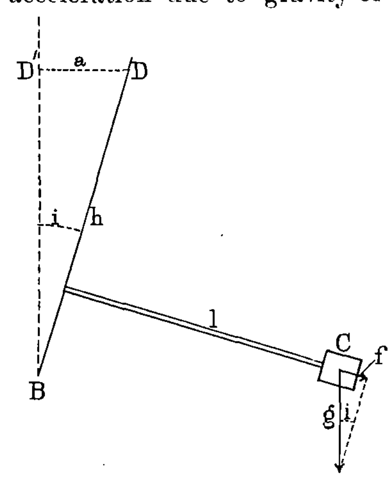

FIG. 3,

causes the pendulum to oscillate. In the case of a horizontal pendulum only a very small component, f, fig. 3, of gravity acts to produce the oscillation, hence the time of oscillation will be reduced in proportion. Thus we have $f = g \sin i$, and the time of a complete vibration is

$$T = 2\pi \sqrt{\frac{l}{g \sin i}}$$

from which

$$\sin i = \frac{4\pi^2 l}{g T^2}$$

which gives the angular inclination to the vertical of the axis of the pendulum corresponding to a given time of vibration T. If h is the linear distance between the two pivot point bearings of the pendulum, then the linear displacement of the upper point from the vertical line through the lower point (that is, $D D' = a$, fig. 3) will be

$$a = h \sin i = \frac{4\pi^2 h l}{g T^2}.$$

It is of great importance to investigate the effects of very small changes in the level on such a pendulum as that now under consideration. It is plain that such influences as variations in temperature, either in the iron column A, fig. 1, or the stone base, or any slight tiltings of the ground will produce changes in the position of the point D with respect to B, the result of which may cause the pendulum to wander from one position of rest to another whenever such changes occur.

Now, while the point D is very nearly vertically above the point B yet in general the distance $D D' = a$ is a magnitude of large order relative to the minute effects of temperature changes or the tiltings of the foundations due to ordinary influences. Thus, for example, in the Weather Bureau pendulum we have the following dimensions: $l = 753$ mm., $h = 958$ mm., $W = 11.4$ kilos. When $T = 25$ seconds, $a = 4.647$ mm. Whereas the displacements due to the influences mentioned are but a few hundredths of a millimeter in magnitude.

Let fig. 4 represent a diagramatic view of the pendulum and magnifying lever, as seen from the top. The point at D' is the end projection of the vertical line through the bottom pivot point B of the pendulum. C is the heavy mass and D is the top pivot.

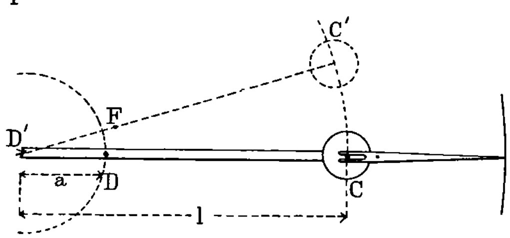

FIG. 4.

Let n = the ratio of the long to the short arm of the magnifying lever. If now we consider the pivot of the lever stationary and the pivot f, fig. 2, to move, then the tracing point will give a record of the displacement of f magnified n times. So likewise, as happens during an earthquake, if C and the pivot f remain at rest and the pivot d, fig. 2, moves with the earth, the magnification will still be n times, since the record sheet is itself displaced an amount equal to that of the pivot.

If now any of the influences mentioned causes a small displacement of the point D exactly in the direction of the line D' C, the only effect will be to alter the time of oscillation of the pendulum. A displacement in any other direction, however, as, for example, to F will not only modify the period, but will cause the pendulum to swing to a new position of rest in the azimuth D' C''. Inasmuch, however, as the distance D D' is relatively large compared with the minute displacements we have in mind, the alteration they may produce in the period is of no consequence whatever and we are therefore now concerned only with the component of displacements perpendicular to the line D' C. We virtually assume that the displacement is tangent to the circle through D with center at D'.

Let ΔD be a small lateral displacement of the point D and let α be the corresponding angular change of the pendulum in azimuth; then $\tan \alpha = \frac{\Delta D}{a}$ and if d is the displacement on the record sheet then $d = n\, l \tan \alpha = \frac{\Delta D}{a} n\, l$ from which

$$\Delta D = \frac{a\, d}{n\, l}.$$

That is, the value of ΔD in linear measure is

$$\Delta D = \frac{4\pi^2 h}{g T^2 n} d.$$

If φ is the corresponding angular tilting of the ground its measure is

$$\sin \varphi = \frac{\Delta D}{h} = \frac{4\pi^2}{g\, n\, T^2} d. \qquad (1)$$

Since for the small angular magnitudes now under consideration, $\sin \varphi$ is proportional to φ we may write—

$$\sin \varphi = \varphi'' \sin 1'' = \frac{4\pi^2}{g\, n\, T^2} d$$

$$\therefore \varphi'' = \frac{4\pi^2 d}{g\, n\, T^2 \sin 1''}. \qquad (2)$$

In which φ'' = the angular displacement expressed in seconds of arc.

It is seen from the last equation that the sensitiveness to angular tilting depends entirely upon the time of vibration of the pendulum, so that two horizontal pendulums of the same time of vibration, but otherwise of different proportions are, nevertheless, equally sensitive to angular tilting of the vertical axis.

It is plain also that if the motion during an earthquake consists of tiltings rather than horizontal displacements the evaluation of the record must be made by means of equation (2).

With $n = 10$, $T = 25$ seconds, and d measured in millimeters.

$$\varphi'' = 0.1329\, d, \qquad (3)$$

$$\text{and } \Delta D = 0.0617\, d. \qquad (4)$$

Equations 3 and 4 give the numerical values of φ'' and ΔD for the Weather Bureau pendulum when the magnification is 10 and the period of vibration is twenty-five seconds. The extreme sensitiveness to tilting is exhibited in several ways. The weight of the observer almost anywhere on the floor of the small room in which the instrument is installed suffices to tilt the pendulum enough to show on the record, a large displacement is produced by standing at one side of the pedestal. It has been noticed also that the weight of an ice wagon which stops daily to deliver ice at a basement entrance to the building causes a definite displacement of the trace of about one millimeter which disappears when the wagon drives away. There are no vibrations or oscillations registered, only a distinct elastic bending of the ground due to the load. This motion, moreover, is communicated through the foundation walls of the building. The distance of the wagon from the seismograph is about 20 feet; the asphalted drive and the basement floor are on the same level. The subsoil is a hard clay.

It may be added that the road is a private driveway back of the building and is rarely used so that the effects and disturbances of the record due to its proximity are not regarded as interfering in the least with the validity of earthquake records.

Aside from transitory tiltings of the ground of the kind just discussed others of a more gradual character are also observed. If the pendulum were to remain absolutely stationary during twenty-four hours the record sheet would contain twenty-four straight parallel lines quite accurately spaced three millimeters apart.

The spacings are never exact, but are sometimes quite uniform. Generally, however, there is a distinct and progressive widening or narrowing of the spacings across the sheet, showing that a slow progressive tilting of the column or the ground has been in progress during the twenty-four hours in question.

While some of these displacements must be attributed to temperature changes and effects entirely within the instrument, yet slow tiltings of the ground also occur, due to a variety of causes. The seismograph, as now installed, answers every purpose for the registration of distinctively earthquake movements, but the slow tiltings referred to can not be studied satisfactorily in the present location of the apparatus which for such purposes should be isolated as far as practicable.

OBSERVATIONS OF SOLAR RADIATION WITH THE ANGSTROM PYRHELIOMETER, AT PROVIDENCE, R. I.[1]

By Mr. HARVEY N. DAVIS, dated March 9, 1903.

During the fall of 1901 arrangements were made by Prof. Cleveland Abbe, on behalf of the United States Weather Bureau, and Prof. Carl Barus, of Brown University, for making a series of observations upon the amount of solar radiation received from day to day at the surface of the earth. An Ångström electric compensation pyrheliometer, No. 28, and a Weston milliamperemeter, No. 4315, were accordingly sent to Providence, R. I., and the work placed in my hands.

As an observing station we finally decided upon a room in the third story of a house situated in one of the highest parts of the city. The galvanometer, resistances, and batteries were permanently fastened to the wall just inside a southern window, while the sloping roof outside offered a convenient and exposed support for the tripod and pyrheliometer. When in position the observing tube was about 188 feet above sea level.

As is already well known,[2] the instrument consists essentially of two thin narrow strips of blackened platinum so mounted as to be exposable to the sun's radiation. While one is thus exposed the other is shielded and heated to the same temperature by the passage of an electric current of known intensity (usually .2 to .4 amperes), the ammeter and a variable resistance being included in the circuit. The desired equality of temperature is recognized by means of a secondary thermoelectric circuit, including a very sensitive galvanometer of the D'Arsonval type, and a constanten-copper thermal element, whose junctions are very close to, but electrically insulated from, the centers of the two strips. At first the instrument was used with its electrical connections just as they were packed, but a considerable shifting of the zero point of the galvanometer soon appeared, and seemed to be due to a set in the torsion suspension, caused by the extreme deflections to which so sensitive an instrument is liable, before the current strength can be properly regulated. On this account I was led to introduce a platinum key into the galvanometer circuit and to use a zero method, adjusting the current in the main circuit until no throw was observable when the key was closed. This key was almost immediately replaced by a mercury commutator, symmetrical with respect to the galvanometer and pyrheliometer tube, to avoid any spurious thermal E. M. F. in the circuit. It was also found convenient to modify the connections of the main circuit for various reasons, until it assumed a form schematically represented in fig. 1. P is the tube, C the commutator, and G the galvanometer of the thermo-couple circuit. In the main circuit r is the variable resistance (which could be made ∞) and M the ammeter supplied with the apparatus. R is a resistance box of considerable size, which was used, partly to cut down the current on cloudy days, and partly to keep two Daniels' cells (B) in condition when the apparatus was not in use. T is a mercury three-way key.

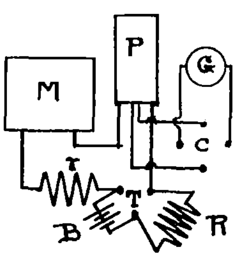

FIG. 1.

Early in December the behavior of the observing tube became very irregular, its resistance often becoming infinite for no apparent reason whatever. It was, therefore, returned to Washington and its contacts thoroughly examined, and, although no trouble could be found, the bad contact was in some way improved, for it functioned properly during the rest of the year.

During the summer of 1902 the writer was obliged to give up the work on account of his absence from the country, and Mr. Robinson Pierce, jr., also of Brown University, very kindly undertook it. The apparatus was moved to a similar situation at his home, a quarter of a mile away on the same ridge, the altitude of the tube being 163 feet. Here observations were made during July, August, and a part of September. Others were made later in September at the first place. Besides making these observations, Mr. Pierce has also carried through a considerable number of the calculations, whose results appear in the accompanying tables.

The method of observing was as follows: The tube was first set up and oriented, both strips being exposed to the sun, and the standard time, the neutral reading of the galvanometer (the key being open) and the temperature inside the tube were recorded. The "throw" when the key was closed was also observed, and both strips were exposed until this was a minimum, and usually very small. Two current determinations were then made, the first with the left-hand strip in the circuit and the second "switch right;" the tube's orientation was corrected; two more determinations were made, the first "switch right" and the second "switch left," and then the time, temperature, and zero point were again observed and recorded. The mean of four such current determinations was taken as the i of the set, corresponding to the mean time and the mean temperature. The total time necessary to complete a set was from four to eight minutes. The state of the sky was also recorded.

The sources of error to which such work is subject are very many. In the first place, a brisk breeze, if it were from the right direction and a bit gusty, was sometimes enough to cause a throw of 2 or 3 centimeters in a scale distance of some 50 centimeters, and the resulting error in the determination of radiation is 5 or 10 per cent. It is almost always possible, however, to take readings between times when the wind is gusty; when it is steady, the effect upon the mean i should be zero, so that this trouble is not particularly formidable if one does not care for accuracy within say 2 or 3 per cent. A further difficulty is caused, on all but the best days, by variations in the amount of heat absorbed by mists or clouds in the path of the sun's rays. If the cloud layers are at all thick, the resulting fluctuations in the radiation received are so considerable and so rapid that anything but the roughest kind of an approximation is at once impossible and meaningless. The presence of either of these difficulties is indicated in the accompanying tables by the words "readings variable," and when a full set of four determinations could not be obtained the resulting radiation number is marked with (?).

INVESTIGATION OF INSTRUMENTAL ERRORS.

Besides these meteorological troubles there were also instrumental ones to be reckoned with. The most obvious of these was a scale error in the ammeter, the pointer of which quite evidently read some 0.008 amperes too low when the instrument was first received. It was accordingly connected in series with a Thomson current balance, No. 134, a variable re-

[1] A similar report by Mr. H. H. Kimball will follow.—ED.

[2] See Prof. C. F. Marvin: "The measurement of sunshine and the preliminary examination of Ångström's pyrheliometer," MONTHLY WEATHER REVIEW, October, 1901.

See also Knut Ångström, Intensité de la Radiation Solaire—Recherches faites à Ténériffe, 1895 et 1896. Upsal, 1900.

See also K. Ångström, Nova Acta Upsal, 1893: The Physical Review, I, p. 365, 1893; Wied. Ann. 67, p. 636, 1899; Astrophysical Journal, 9, p. 334, 1899, and Annalen der Physik und Chemie, Neue Folge, Band 67 [1899], p. 633.